Production Optimization of Unconventional Reservoirs Through Multi-Disciplinary Collaboration

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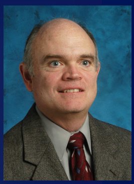
Stuart is a Society of Petroleum Engineers Distinguished Lecturer 2009-2010. In 2012 he received the Gulf Coast Region Formation Evaluation Award.
He graduated from the University of Tulsa with a B.S. degree in Petroleum Engineering in 1984 and is a registered professional engineer in Alaska and Oklahoma.



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Goals

Provide techniques to improve the post completion evaluation of well performance.

Present techniques for production forecasting and economic planning.

Highlight the importance of an integrated approach.

Comments on Production Optimization

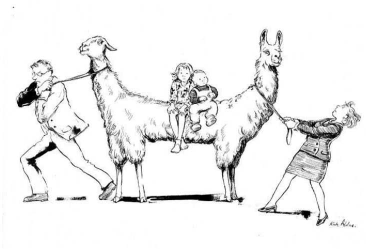
Production optimization of unconventional developments requires adequate characterization of the reservoir and an in-depth understanding of the factors that control flow capacity and deliverability.

Production optimization also requires a consistent focus across company teams working towards a common goal.

The measure of success will depend on your definition of production optimization.

If your company lacks a common focus or goal you my find yourself in this situation:

Comments on Production Optimization



http://www.katealdousillustrator.com

Comments on Production Optimization

Possible definitions

– Maximizing near term cumulative production
  - Minimizing spacing (well / stages)
– Maximizing recovery per well
  - Optimizing spacing (well / stage)
– Maximizing economic return
  - Balance Spacing (well / stage)

Your development / completion strategy should be consistent with your definition

Poll Question - Production Optimization Evaluation Techniques

How will you evaluate your performance?

Production Optimization Evaluation Techniques

- Rules of thumb
  - Completion practices
  - Initial performance
- Fracture stimulation execution
  - Pre/Post job analysis
  - Are results predictive
- Rate time analysis
  - Peak monthly rate
  - Offset type curves
  - Decline curve analysis
- Rate time and pressure analysis
  - Production analysis
  - Reservoir simulation

Outline

- Actual performance of North American Plays
- Common flow regimes
- Decline analysis workflow
- Well spacing work flow
- Data requirements
- Production optimization
  - Reservoir and completions parameters
  - Field development workflow
- Production optimization workflows

Decline Considerations

Past performance trends are characterized mathematically to predict future performance

What contributes to an unconventional well's decline character?

- Reservoir considerations
  - Initial reservoir pressure
  - Flow capacity
  - Fluid type
  - Rock properties
- External considerations
  - Completion practices
  - Operational constraints

Review Historical Performance Horizontal Completions

Tight Oil Performance

- Austin Chalk
- Bakken
- Barnett
- Eagle Ford
- Niobrara
- Woodford

Shale Gas Performance

- Austin Chalk
- Barnett
- Eagle Ford
- Fayetteville
- Haynesville
- Woodford

Which play has the highest / lowest initial decline?
What about the minimum long term decline?

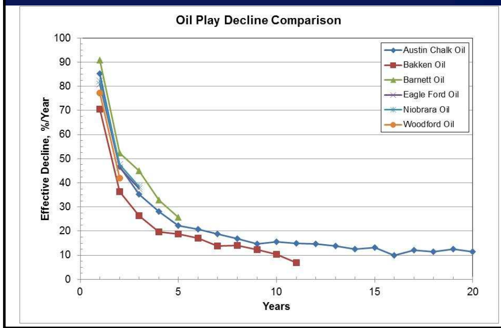
Poll Question - Oil Play Decline

Which play has the highest initial 12 month decline?

Poll Question - Oil Play Decline

Which play has the lowest initial 12 month decline?

P50 – Oil Well Declines by Play



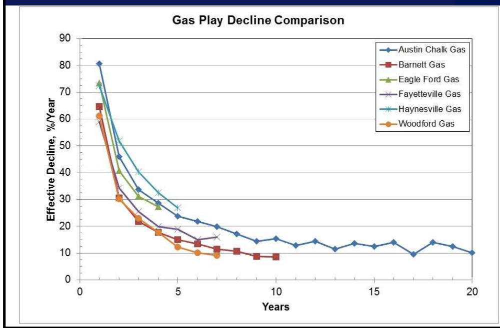
Poll Question - Gas Play Decline

Which play has the highest initial 12 month decline?

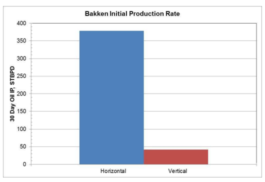
Poll Question - Gas Play Decline

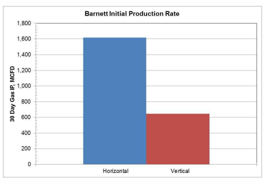
Which play has the lowest initial 12 month decline?

P50 – Gas Well Declines by Play



Why Horizontal Wells?



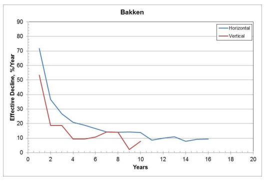


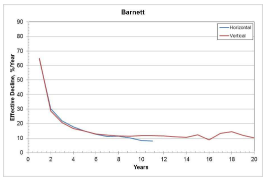
A comparison of horizontal & vertical IP30 rate shows the benefit

SPE 175993 • A Comprehensive Approach to Rate-Time Production Analysis for Unconventional Resources

Long Term Performance

Webinars





A comparison of horizontal & vertical decline performance shows the benefit

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Flow Regime Analysis
Common Flow Regimes

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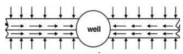
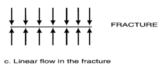
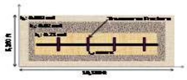
- Transient Bilinear flow
  - Diagnostic slope ¼



- Transient Linear flow
  - Diagnostic slope ½



- Boundary Influenced flow (BIF)
  - SRV dominated flow
  - Diagnostic slope near 1



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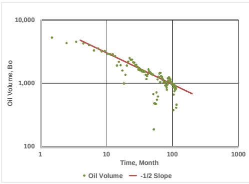
Production Optimization
Flow Regime Identification

Webinars

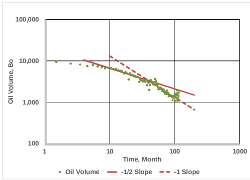
- Construct a Log-Log rate-time diagnostic plot
- Obtain Best fit – ½ slope line
  - Transient Linear Flow Period
- Check - ½ slope fit to determine if a unit slope would better fit the data
  - Identify transition to boundary influenced flow period
- Final flow period maybe dominated by well spacing or the far field depending on the unstimulated flow capacity
  - Boundary influenced flow
  - Transient linear flow

Bakken Example

Long Term Linear Flow



Transition to BIF Flow



The incorporation of flow regime analysis will result in more consistent decline projections and improve our estimates. All decline projection should include a terminal decline.

Decline Curve Analysis Proposed Workflow

- Perform flow regime analysis
  - Determine transition times
- Limit decline projections to a single flow regime
  - Change decline parameters as flow regimes change
- Base ultimate recovery projection on the results from the BIF period including an appropriate terminal decline
- Be aware of the flow regime your well is in during the curve fitting period
- Always include a terminal decline
  - Decline projection during transient flow may require a higher terminal decline than those during BIF

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Poll Question - Should a Terminal Decline be Used and What is an Appropriate Value?

Do you use a terminal decline?

Poll Question – Should a Terminal Decline be Used and What is an Appropriate Value?

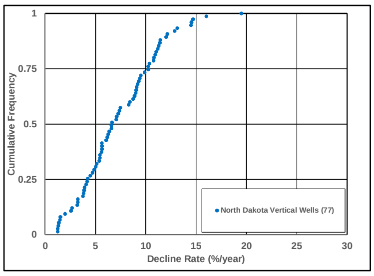
What range is appropriate?

Terminal Decline Considerations

- Terminal Decline is one way of accounting for changing flow regimes
  - A predetermined decline character which is used to limit the decline projection. It is commonly used to transition from a hyperbolic character to an exponential character.
- What should it be based on?
  - Vertical well performance
  - Industry accepted values
- Should it be the same for every well in the development?
  - Reservoir properties
  - Completion strategy
  - Well Spacing

Bakken Terminal Decline Example

Slide 27



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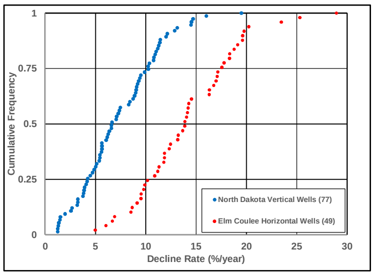
Bakken Terminal Decline Example



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Well Spacing Work Flow

- Define the objective for the test
- Perform conceptual modeling work for the area based on well results and geologic model
  - Define timing
  - Define spacing requirements
- Ensure that your test is bounded

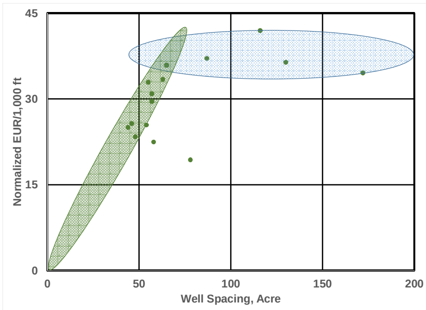
Spacing Analysis

Proposed Workflow (Public Data)

- Decline Curve Analysis
  - Obtain production data
    - Similar reservoir and fluid properties
    - Drilled at various well spacing
  - Project EUR for each well
    - Normalize projection / 1,000 ft
  - Determine well spacing
    - Completed lateral length X average of offset spacing
      - Pick a maximum distance if no offset (2,000 ft)
  - Plot normalized EUR versus well spacing
    - Evaluate trends

Note this analysis combined with an economic evaluation can be used to determine level of production optimization

Field Study
15 Well Example



Production Optimization
Data Requirements

- Detailed geologic description
  - In place volumes
  - Initial reservoir pressure
  - Fluids in place
  - Mechanical properties of the formation
  - Reservoir flow capacity (static / dynamic)
- Incorporate geologic description into a predictive model of reservoir performance
  - Initial rate
  - Production profile
  - Recoverable reserves

Production Optimization
Reservoir Parameters

- Fluid in Place
  - Log and core analysis
    - Limit estimates to the portion of the reservoir that is contributing to performance
      - Note: If the landing zone is important the vertical contact area may also be limited
- Reservoir Pressure
  - Drilling records
  - DFIT analysis (SPE 169539 and 107877)
- Flow capacity
  - Static or background
    - Core analysis
    - Rule of thumb for post stimulation economic deliverability
      - Gas reservoirs minimum background permeability ~10 nanoDarcy
      - Oil reservoirs minimum background permeability ~100 nanoDarcy
  - Dynamic (post stimulation – SRV)
    - From DFIT analysis (SPE 169539 and 107877)
    - Post completion production analysis **(Analytical/Numerical analysis of rate, time and pressure data)**
    - Typically 10 to 100 times the core permeability in productive intervals

Production Optimization
Completion/Production Parameters

- Lateral length
  - As we increase our lateral lengths how does your well performance improve?
  - Do longer laterals always improve our economics?
- Other completion parameters that contribute to performance
  - Stage Spacing
  - Cluster spacing
  - Flow back strategy
  - Production limits

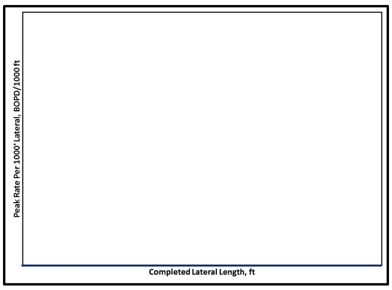
How can we evaluate the efficiency gain associated with changing these parameters?

(well performance evaluation and economics)

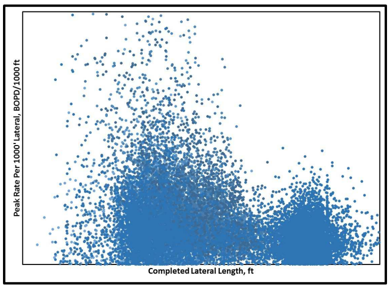
Completion/Production Parameters
Well Performance

- Define a study area
  - Fluid properties
  - Reservoir parameters
  - Completion type
- Define a plotting parameter
  - IP 30
  - 12 month ….. Cumulative production
  - Ultimate recovery from properly constrained decline projections
- Always normalize your results (completed lateral length)

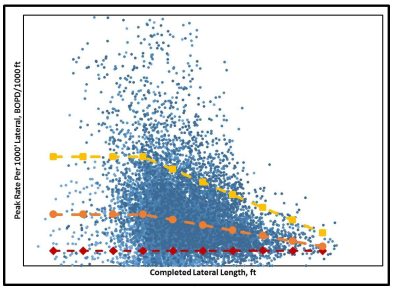
Plot
Normalized Peak Month



24,455 Wells
Normalized Peak Month



Single Development
Normalized Peak Month

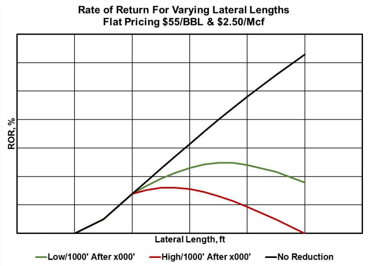


Implication related to type curve construction and economics

Economic Considerations

- Type curve construction
  - Completion and reservoir quality
  - Completion lengths
  - Well Spacing
- Drilling and Completion costs
  - Relatively fixed cost for vertical section
  - Variable cost for horizontal section

Economic Analysis
ROR vs Completion Interval



Results show the importance including completion efficiency effects into the analysis

Production Optimization
Completion/Production Parameters

Other Considerations

- How does stage and cluster spacing affect rate and ultimate recovery?
  - As stage spacing is reduced initial rate will increase
  - Ultimate recovery
    - Contact new reservoir
    - Does not contact new reservoir
- Flow back strategy and Production limits
  - Define your goal
  - Evaluate your results

Proposed Workflow
Stage and Cluster Spacing

1. Estimate static and dynamic reservoir parameters
   a. Historical well performance
   b. Hydraulic fracture modeling
2. Evaluate results based on well spacing for the development
3. Incorporate reservoir description and development spacing into an appropriate analytical of numerical simulator
4. Evaluate performance
   a. Initial production
   b. Decline shape (transient flow, BIF and terminal decline)
   c. Well spacing
   d. Ultimate recovery
5. Incorporate results into economic model

Bakken Example

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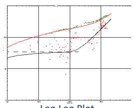
Static Model

BAKKEN	Properties	North Dakota
Reservoir	Reservoir Pressure, psi	8000
	Reservoir Temperature, °F	240
	Permeability, md	0.001-0.06
	Porosity, %	4-6
	Middle Bakken Thickness, ft	30-50
Fluid	API, °	42
	Gas-Oil Ratio, Mscf/bbls	500-800
	Viscosity, cp	0.3-0.5

Production analysis Results Vertical Offset

- Effective radius 2,500 ft
- Flow capacity 1.2 md-ft
- Fracture Xf 250 ft
- Terminal decline 9.8 %


Log-Log Plot

Results from the static interpretation and production analysis were incorporated into a numerical simulation to evaluate peak 30 day rate, terminal decline and ultimate recovery as a function of stage spacing.

SPE 149273 • Evaluation of Long-Term Performance of Oil Wells in Elm Coulee Field

Bakken Example Results

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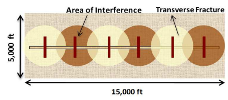
Stages	Implied Spacing Ft	30-Day Rate Bbl/Day	Terminal Decline %/Year
2	7,500	114	4.2
4	3,750	227	9.4
8	1,875	454	12.8
16	938	794	13.4
32	468	711	13.8
64	234	642	14.6



Note: Results are dependent on reservoir and SRV flow capacity, effective fracture half-length and well drainage area.

Bakken Example
Model Results vs. Decline Projections

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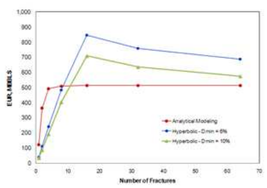


The number of stages required is a function of stimulated reservoir flow capacity and reservoir quality. As the flow capacity reduces the required number of stages will increase. An economic evaluation in conjunction with the these results is also required to determine the optimal stage spacing.

Production Optimization Rate Time Analysis

- Widely used technique
  - Evaluate prospects and developments
  - Predict future performance
  - Evaluate completion efficiency
    - Limited to wells with similar reservoir properties

Production Optimization Production Analysis

- Extends rate time analysis techniques to include rate, time and pressure
- Long term production and pressure data is evaluated through transient analysis techniques to predict reservoir properties and future performance
- Based on transient testing techniques where the production history is treated as a long term drawdown test
- Can be used to discriminate reservoir flow capacity from completion effects

Production Analysis Work Flow

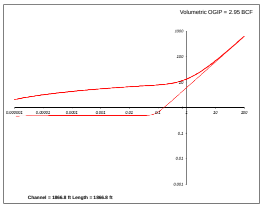
- Gather and prepare well data
  - Well production rates and pressures
  - Wellbore geometry
- Calculate/ Estimate flowing bottom hole pressures
  - If public data make a reasonable and consistent estimate
- Define fluid, reservoir and completion properties
- Perform type curve matching
  - Drainage volume
  - Reservoir flow capacity
  - Completion skin or effective fracture half-lengths
- Compare prediction to actual performance
- Use results to optimize field performance

Production Analysis Results

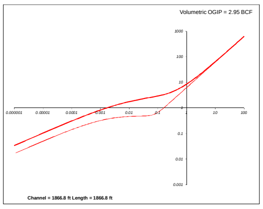
- Production analysis results are non unique
  - Rarely see all flow regimes
- However the analysis can provide meaningful comparisons from well to well in the same field or development if care is taken to follow a consistent workflow
- Type curve shapes provide the first indication of completion efficiency

Production Analysis Type Curve Example

Natural Completion No Skin Damage



Fracture Stimulated



Infinite Conductivity Fracture, Xf = 100 ft

Observations and Conclusions

- Production optimization requires a consistent focus across company teams working towards a common goal.
- Decline projection should be limited to a single flow regime and modified as flow regimes change.
- Production should be normalized to a common length when comparing performance.

Observations and Conclusions

- Well performance data has a negative trend with lateral length after an optimum length. The optimal length should be determined from well performance evaluation and then incorporated into our type curve construction and development planning.
- Well spacing test should be properly constrained in order to provide useful results.
- Production analysis techniques should be included in our analysis and evaluation of well performance.

Thank you!